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Short Communication

Carbon Sequestration of Above Ground Biomass Approach in the Rehabilitated Mangrove Stand at Jepara Regency, Central Java, Indonesia

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Abstract

Among its many advantages, mangroves have a function as carbon sequestration and storage. The aim of this study was to determine the differences in the ability of various rehabilitated mangrove species of carbon Sequestration of Above-Ground Biomass. This study was conducted from June 2020 to December 2021 in Kedung, Mlonggo, and Keling Subdistricts, Jepara Regency, Central Java, Indonesia. The mangrove plantation was a result of a rehabilitation programme sponsored by a society and the local government since 2009. Carbon sequestration measurement in tree biomass was estimated by a non-destructive method *i.e.,* by measuring the Diameter at Breast Height (DBH). Statistical analysis to determine the relationship between carbon storage in several species of mangroves and the environmental factors were performed using XL stat 2022. There were 4 (four) mangrove species found *i.e., Avicennia marina* (Forssk) Vierh, *Rhizophora apiculata* (Blume), *Rhizophora mucronata* (Lamk), and *Sonneratia alba* Sm. The highest CO_2 absorption (397.21 tons ha^{-1}) was obtained both in Kedung and Mlonggo stations with *R. mucronata*, whereas in Keling station with *R. apiculata* the absorption was 54.27 tons ha^{-1}. The results of Principal Component Analysis (PCA) showed that the number of trees and DBH had a relationship with biomass, carbon content, and carbon absorption. Diameter at Breast Height in mangrove species can be used as indicators to assess carbon sequestration in Above Ground Biomass.

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1. Introduction

Jepara Regency as one of the districts in Central Java, Indonesia, is located at 5°43`20.67" to 6°47` 25.83" South Latitude and 110°9`48.02" to 110°58` 37.40" East Longitude. Mangrove community is known as a unique ecosystem with low biodiversity. In Jepara, mangroves continue to experience an increase in population, forming a forest through the rehabilitation processes. The progress of mangrove rehabilitation also gradually supports the survivability of other organisms. Mangrove ecosystems have various functions, *i.e.*, as habitat of organisms (Ariyanto *et al.*, 2020), a source of bioactive compounds, proximate content (Ariyanto *et al.*, 2019b), nitrogen (N), phosphorus (P), potassium (K), Boron (B), Manganese (Mn), and Iron (Fe) producers (Ariyanto *et al.*, 2019c), as well as producing antimicrobial compounds (Pringgenies *et al.*, 2021). More recently, mangrove ecosystem proved to have another function in global warming mitigation, serving as a carbon absorber and storage (Peñaranda *et al.*, 2019).

Mangroves are known as blue carbon forests in the world and play a role in carbon sequestration (Kandasamy *et al.*, 2021), which was estimated at 14.2 TgC yr−1 and per unit area at 1.71 ± 0.17 Mg C ha−1 yr−1 (Alongi, 2018). Being characterized by high density of organic carbon (OC) storage causing high rates of mangrove deforestation to lower its capability to reduce anthropogenic emissions of greenhouse gases (Kauffman *et al.*, 2014) since the concentration of CO_2 may change the primary productivity of mangroves due to the photosynthesis processes (Woodroffe *et al.*, 2015; Atwood *et al.*, 2017; Almahasheer *et al.*, 2017; Supriharyono, 2021).

Adaptation and mitigation strategies to climate change impacts are also due to mangroves having the ability to protect coastal zone and therefore maintaining sustainable fishpond zone to implement silvofisheries (Sutrisno *et al.*, 2021). Mangroves may balance between waves and tides resulting in a stable chenier in the nearshore (Tas *et al.*, 2022). Furthermore, Osland *et al.*, (2020) stated that long-term effects of cyclone-induced ecological regime shifts are due to the conversion of mangrove forests to mudflats. Mangroves have the ability to store most of their carbon stocks in above and below ground biomass (Donato *et al.*, 2011). This study focused on the upper part due to the lack of allometric equations for below ground biomass and the lack of accuracy in estimating mangrove roots (Komiyama *et al.*, 2008). This is also supported by several studies on general allometric equations developed in below ground biomass and carbon stocks that have not provided accuracy (Hamilton and Friess, 2018).

Mangroves in Jepara Regency are the result of rehabilitation activities of local community, institutions, and government agencies. The planted species include *Rhizophora mucronata*, *Rhizophora apiculata*, *Sonneratia alba,* and *Avicennia marina*. These mangroves have their respective advantages in terms of growing and developing in tidal areas. As such, *Rhizophora mucronata* is tolerant of heavy metals (Ganeshkumar *et al.*, 2019; Nualla-ong *et al.*, 2020). *A. marina* is the main species of mangrove that grows in this area either as a pure stand or in mixed with *R. mucronata* (Mutairi *et al.*, 2012). A marina has a good growth when it is longer submerged in high tide. *R. apiculata* affects water quality, microbiota, and growth characteristics of marine biota (Dai *et al.*, 2020). Meanwhile, *S. alba* provides an abundant sequence source for future genetic diversity, salt adaptability (Chen *et al.*, 2011), and short fruiting time patterns with respect to seasons (Wang'ondu *et al.*, 2013). Furthermore, mangrove can support a carbon sequestration depending on sediment stability (van Bijsterveldt *et al.*, 2020), an environmental condition (Chatting *et al.*, 2020; Swangjang and Panishkan, 2021), the organic carbon (Kusumaningtyas *et al.*, 2019; Gao *et al.*, 2019) and mangrove planting (Monga *et al.*, 2022). Mangrove management practices are also needed to support sustainable carbon sequestration dynamic (Hanggara *et al.*, 2021).

Mangrove stands have great potential in absorbing CO_2 from the atmosphere and storing it in the form of body biomass. The concentration of CO_2 can change the primary productivity of mangroves due to the process of photosynthesis (Almahasheer *et al.*, 2017; Supriharyono, 2021). The process of carbon absorption is also supported by the decomposition process (Ariyanto *et al.*, 2018) of the physicochemical factors and litter dynamics (Ariyanto *et al.*, 2019a). Land use can affect the existence of carbon stocks in the mangrove environment (Zakaria *et al.*, 2021). Climate has the effect of decreasing 14.6% of the total carbon stock (Gomes *et al.*, 2021). The potential of mature plantations can enhance carbon stocks (Wang *et al.*, 2021), mangrove blue carbon for climate change mitigation (Zeng *et al.*, 2021), and associated carbon stock and potential emissions of mangroves (Aljenaid *et al.*, 2022). Adaptation and mitigation strategies to climate change impacts in the mangrove ecosystem are supported by mangroves having the ability to store organic carbon (OC) for a long time (Woodroffe *et al.*, 2015; Atwood *et al.*, 2017). The aim of this study was to determine the differences in the ability of various rehabilitated mangrove species in Jepara Regency to carbon Sequestration of Above Ground Biomass.

2. Materials and Methods

2.1 Timeline and Location

This study was conducted from June 2020 to December 2021 in three sites, *i.e.*, Kedung, Mlonggo and Keling subdistricts; in each site three sampling points have been sampled (Figure 1). The coordinates of each location are C1 (Kedung): 6’39”060 S 110’38”760 E, C2 (Mlonggo): 6’30”420 S: 110’40”380 E, and C3 (Keling): 6’24”600S, 110’50”400 E. Sample collections were taken three replications (C1=1,2,3; C2 =4,5,6; C3 =7,8,9) and sampling point was determined by means of purposive sampling methods, considering density, growth stadia, diameter at breast height, and dominance of the mangroves. Data was analyzed in the Integrated Laboratory of The Diponegoro University, Semarang.

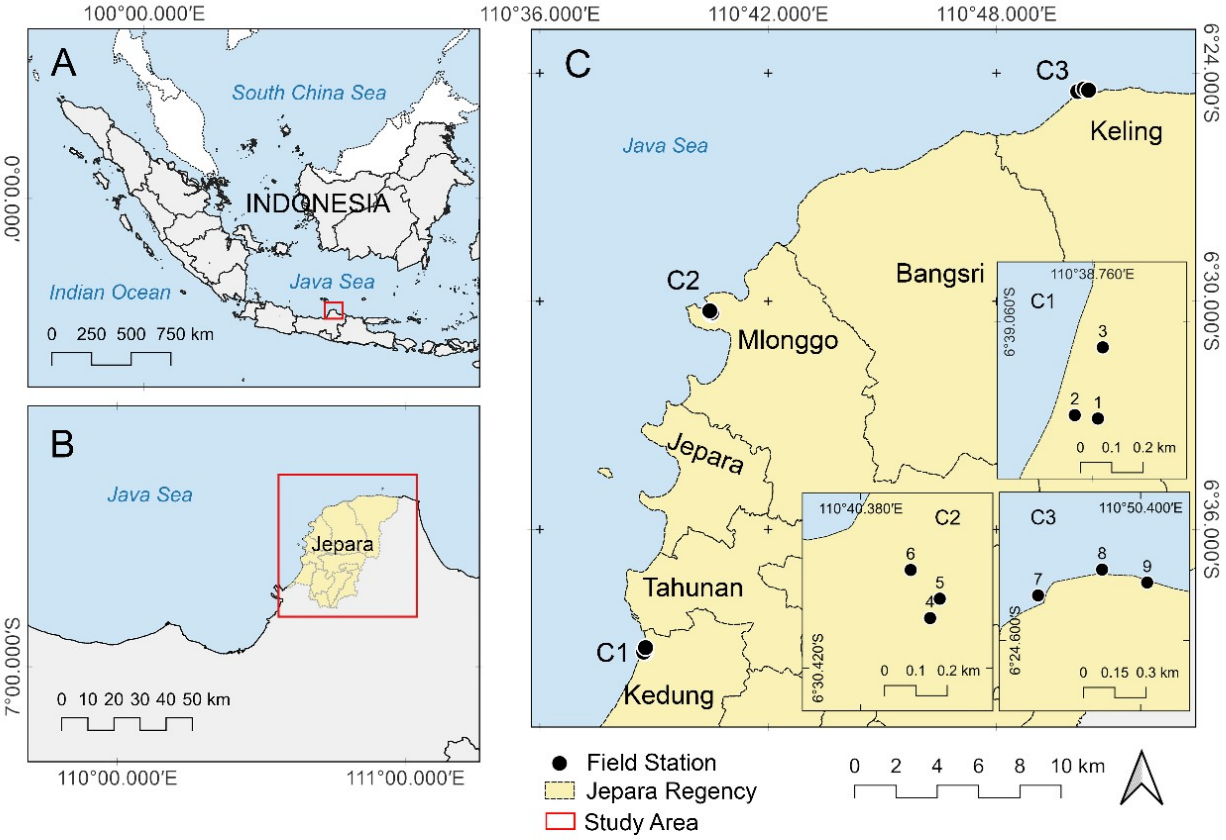

Figure 1. Study locations in three subdistricts (small and large black dots) of Jepara Regency, Indonesia

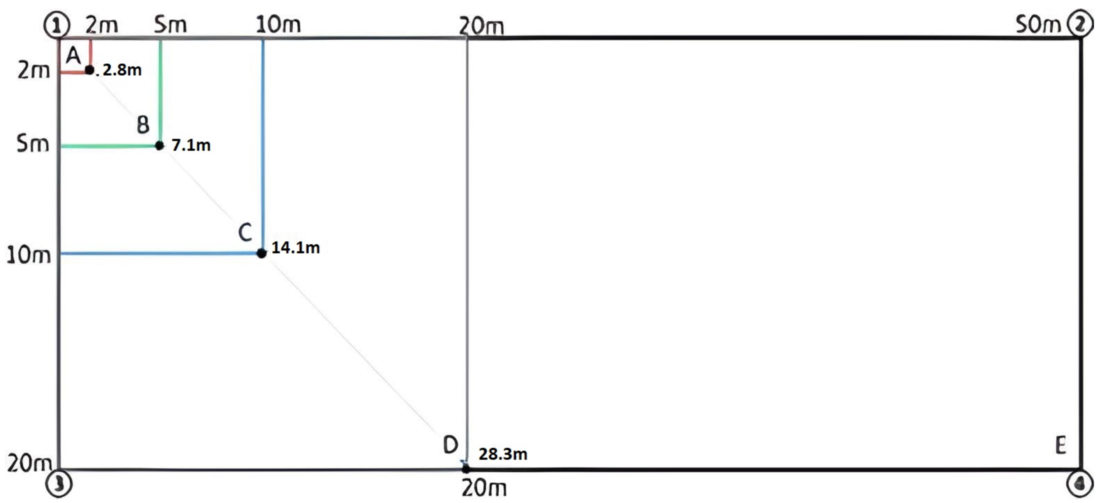

Figure 2. Transect plot for data collection of tree stem diameter in mangrove

2.2 Working Procedure

2.2.1 Sampling (mangrove)

The mangroves at the study site were the result of rehabilitation since 2009. Sampling of mangroves based on mangrove planting consisted of *R. mucronata*, *R. apiculata*, *A. marina*, and *S. alba* which tended to cluster in one planting location. Mangrove identification samples consist of leaves, fruit, flowers, and roots on *R. mucronata, R. apiculata, A. marina, S. alba.* Determination of this species is based on guidelines (Anwar *et al*., 2003). The plot shape used in this study was a square or rectangle, so that it was easy to monitor. The shape and size of the plot was a standard size that follows SNI (Indonesian National Standard) 7724 (2011) (Figure 2).

The mangrove transect plot followed the contours of the area. Each station has three transect with 10 m x 10 m and the same distance between plots and width. The plot size was 10 m x 10 m to measure trees > 5 cm in diameter (Kauffman and Donato, 2012). The sample data was collected on low tide condition. The primary data collected in the sample plots related to mangrove stands included the tree species, tree diameter at breast height (1.3 m above ground level) using a diameter tape and branch-free tree height.

2.2.2 Environmental variables

Some routine environmental physical parameters were measured. Physical parameter consisted of water quality (pH, dissolved oxygen, temperature, and salinity) using a water quality instrument (model AZ 8603, China) and sediment texture.

2.3. Data Analysis

2.3.1 Mangrove density

The density of each species was calculated from the results of the stands calculation in a certain area in individual units/m^2. The relative observation was the percentage density of each species in the transect. The relative density value was obtained by equation (Rachmawati *et al*., 2014):

RD = 100% (Di/D)

Note: RD = Relative Density, D_i = Individual density of each species i, D = Total individual density

2.3.2 Biomass

Tree biomass estimation was conducted using a non-destructive sampling method by measuring the Diameter at Breast Height (DBH) (Table 1). Calculations with allometric models were performed to estimate the potential of biomass and its carbon storage. The above-ground biomass (Diameter at Breast Height, Biomass wood density) calculation used an allometric equation that was in accordance with the characteristics of the measurement location. These include the climatic zone, forest type and if possible, the species name or group of species. Determination of mangrove biomass for each species in this study used the above-ground biomass allometric model (Rusolono *et al*., 2015).

Table 1. Above-ground biomass allometric model

Species type	Allometric model	Source
Rhizophora apiculata	$B = 0.0043*D^{2.63}$	(Amira, 2008)
Avicennia marina	$B = 0.1848*D^{2.3524}$	(Dharmawan and Siregar, 2008)
Rhizophora mucronata	$B = 0.1466*D^{2.3436}$	(Dharmawan, 2010)
Sonneratia alba	$B = 0.3841\rho D^{2.101}$	(Kauffman and Cole, 2010)

Note: B = Biomass (kg); D = *Diameter at Breast Height* (cm); ρ = *wood density* (gr/cm^2)

2.3.3 Carbon storage

The tree biomass allometric model approach was developed for a species or ecosystem that will be predicted in a certain location which was not/not yet available, but a tree biomass allometric model for that ecosystem type/species was already available or developed in other locations (Krisnawati *et al*., 2012). Estimation of carbon stock based on biomass requires the value of the biomass conversion factor to carbon stock called the carbon fraction. Values for carbon fractions of specific species or ecosystem types that are not available can be calculated using IPCC (Intergovernmental Panel on Climate Change) default value of 0.47 (Pachauri and Reisinger, 2007).

Carbon Stock = 0.47 × Biomass

Conversion of carbon stock to CO_2 – equivalent can be determined using the ratio of the relative atomic mass of C (12) to the relative molecular mass of CO_2 (44) formulated through the following equation:

CO_2 – equivalent = (44/12) x carbon stock

2.4 Statistical Analysis

This research used XL Stat 2022 on processing data. Analysis statistic used to know the relationship between sequestration and environmental factor.

3. Results and Discussion

3.1 Mangrove Density

The relative density of various mangrove types and locations in Jepara Regency, Central Java (Table 2). In the location of Kedung (T), three mangrove species were found: *A. marina*, *R. apiculata*, and *R. mucronata*. The highest relative densities order was *R. mucronata* > *R. apiculata* > *A. marina*. Meanwhile, in Mlonggo, three mangrove species of *A. marina*, *R. apiculata*, and *R. mucronata* were also found, and the highest relative densities order were *R. mucronata* > *R. apiculata* > *A. marina*. Four species of mangroves were found in Keling (K) subdistrict: *A. marina*, *R. apiculata*, *R. mucronata* and *S. alba* (Table 2). Each with the number of trees as follow: *S. alba* (2 trees), *R. mucronata* (5-10 trees), *R. apiculata* (1-2 trees), and *A. marina* (3 trees). The highest relative density values in Keling (K) order were *R. mucronata* > *R. Apiculata* > *S. alba* > *A. marina*.

Types of mangroves found at the sites included *Avicennia marina* (Forssk) Vierh., *Rhizophora mucronata* (Lamk), *Rhizophora apiculata* (Blume), and *Sonneratia alba* Sm. The highest biomass content of *R. mucronata* at Kedung site was 235.28 tons ha^{-1} and the lowest was 8.42 tons ha^{-1} (Table 3). At Mlonggo site, the highest biomass content was achieved in *R. mucronata* of 235.28 tons ha^{-1} and the lowest was in *A. marina* of 41.60 tons ha^{-1}. At the Keling site, *R. apiculata* obtained

Table 2. Relative density of mangroves at the study locations (100 m-2)

Location	Mangrove Type	Seedling	Sapling	DBH (cm)	Tree	RD (%)
C1.1	*A. marina*	15	35	10	2	9.09
	R. mucronata	15	20	15	20	90.91
C1.2	*A. marina*	0	2	10	6	20.69
	R. apiculata	0	7	13	20	68.97
	R. mucronata	0	0	18	2	6.9
C1.3	*R. mucronata*	0	11	5	11	84.62
	R. apiculata	46	46	10	2	15.38
C2.4	*R. apiculata*	10	8	15	2	33.33
	R. mucronata	0	1	10	4	66.67
C2.5	*A. marina*	0	21	12	18	90
	R. mucronata	0	0	18	2	10
C2.6	*A. marina*	0	0	10	2	25
	R. mucronata	10	2	15	6	75
C3.7	*R. mucronata*	15	3	8	10	71.43
	R. apiculata	10	10	6	5	7.14
	S. alba	2	1	7	2	79.37
	A. marina	0	2	5	3	21.43
C3.8	*A. marina*	0	0	5	2	20
	R. mucronata	5	21	5	6	60
	R. apiculata	0	1	7	2	20
C3.9	*R. apiculata*	0	0	10	1	4.76
	R. mucronata	74	51	8	5	80.95
	A. marina	0	22	7	3	14.29

Note: Kedung **(**C1**),** Mlonggo (C2), Keling (C3), Replication (1,2,3,4,5,6,7,8,9)

Table 3. Estimation of above-ground biomass and carbon sequestration

Location	Type	Biomass (ton ha^{-1})	Carbon (ton ha^{-1})	CO_2 sequestration (ton ha-1)
C1.1	*A. marina*	41.6	19.14	70.23
	R. mucronata	146.46	67.37	247.25
C1.2	*A. marina*	41.6	19.14	70.23
	R. apiculata	63.67	29.29	107.49
	R. mucronata	235.28	108.23	397.21
C1.3	*R. mucronata*	8.42	3.87	14.21
	R. apiculata	31.85	14.65	53.77
C2.4	*R. apiculata*	92.91	42.74	156.85
	R. mucronata	51.04	23.48	86.16
C2.5	*A .marina*	63.88	29.38	107.84
	R. mucronata	235.29	108.23	397.21
C2.6	*A. marina*	41.6	19.14	70.23
	R. mucronata	146.46	67.37	247.25
C3.7	*R. mucronata*	28.57	13.15	48.23
	R. apiculata	8.26	3.8	13.96
	S. alba	1.78	0.82	3.02
	A. marina	8.15	3.75	13.75
C3.8	*A. marina*	8.15	3.75	13.75
	R. mucronata	8.42	3.87	14.21
	R. apiculata	12.52	5.76	21.14
C3.9	*R. apiculata*	32.15	14.78	54.27
	R. mucronata	28.57	13.14	48.23
	A. marina	17.98	8.27	30.34

Note: Kedung **(**C1**),** Mlonggo (C2), Keling (C3), Replication (1,2,3,4,5,6,7,8,9), DBH (Diameter at Breast Height)

the highest biomass compared to the other mangroves, which was 32.15 tons ha^{-1}. The highest carbon sequestration of CO_2 ton ha^{-1} at Kedung site was found in *R. mucronata* with 397.21 tons ha^{-1}. At Mlonggo site, the highest CO_2 sequestration was achieved in *R. mucronata* with 397.21 tons ha^{-1}, while at Keling site, the highest CO_2 sequestration was obtained in the mangrove *R. apiculata* with 54.27 tons ha^{-1}. The higher biomass of a tree will result in the higher carbon sequestration. The tree biomass is also affected by the number of trees and the value of tree DBH. Mangrove species also affects biomass and carbon sequestration. This study revealed that the mangrove species *R. mucronata* had high CO_2 absorption capacity compared to other species of *R. apiculata*, *S. alba*, and *A. marina*.

Areas with dense vegetation classification have observation trees with older plant ages, so that they have a larger tree diameter than areas with sparse classification. This affects the average amount of carbon contents. The value of carbon stock in mangrove forests will increase in line with the increase in biomass. The greater biomass content results in the greater carbon stock. According to Kauffman and Donato (2012), the carbon concentration in organic matter is usually 50%, so that the carbon storage in the stem is 50% of the biomass. However, the carbon storage in the roots is 39%. The amount of biomass is affected by the tree's diameter. The larger diameter of the tree results in the greater tree's biomass. The larger the tree's diameter, the more CO_2 the tree absorbs. Plants absorb CO_2 from the air and convert it into organic compounds through the process of photosynthesis. Mangrove stands have great potential to absorb carbon.

Carbon losses occurring in affected forests include above-ground tree carbon loss, stock collapse, and topsoil carbon loss (Osland *et al.*, 2020). The greater amount of carbon stored is influenced by the high soil fertility and plant growth (Rusdiana, 2012). The amount of carbon stored in the mangrove *R. apiculata* aged 1 year, 3 years and 5 years was 0.363, 5,591, and 7,240 tons ha-1, respectively (Wiarta *et al.*, 2019). The average above and below-ground C stocks were 48.6 ± 11.7 and 554.8 ± 112.2 MgC ha-1 (Tue *et al.*, 2020). Carbon stock and sequestration of *A. marina* varies according to age and vegetative characteristics, and carbon absorption of *A. marina* is highly dependent on soil nutrients (Kandasamy *et al.*, 2021). Comparison of this research with other studies shows that the total carbon stock of above ground carbon in Sulaman Lake Forest Reserve, Malaysia showed a higher above ground carbon content than below, *i.e.*, above ground carbon (67.30± 20.55 Mg C ha-1) and below ground carbon (22.44± 0.17 Mg C ha-1) (Suhaili *et al.*, 2020). Research in the mangrove rehabilitation of Sulawesi also showed above and below ground biomass of 125.48±93.48 Mg C ha-1 and 60.23±44.87 Mg C ha-1, respectively (Malik *et al.*, 2020); while in Bintuni Bay, the above and below ground live biomass carbon stocks were 96 ± 65 and 17 ± 16 Mg C/ha, respectively (Sasmito *et al.*, 2020). In Tanzania, the above ground carbon (AGC) and below ground carbon (BGC) of the good natural mangrove plots ranged from 28.18 – 299.43 and 16.00 – 164.51 Mg C ha−1 (Monga *et al.*, 2022).

3.2 Environmental Variables

Environmental parameter measurements included pH, dissolved oxygen (DO), temperature and salinity at the study sites (Table 4). The pH conditions range from 7.6 – 8.4, while DO ranges from 5.2 – 6.6 mg L^{-1}. There was no difference in salinity conditions at the three study sites. In general, the sediments texture conditions at the three sites were sandy mud and coral sand mud.

3.3 The Relationship between Carbon and Mangrove Species

This study used PCA (Principal Component Analysis) to describe the relationship between carbon stock and environmental conditions (Figure 3). There was factor 1 and factor 2 of 70.30% consisting of F1 (49.0%) and F2 (21.29%). The number of trees and DBH had a relationship with biomass, carbon content, and carbon sequestration. The more trees that grew and developed with a large DBH size affected the biomass, carbon content, and carbon sequestration of mangroves. This study also revealed that relative density had no relationship with mangrove carbon sequestration.

The result showed that environmental factors of pH and DO have a positive relationship*, i.e.,* the higher the DO, the higher the pH value. Temperature and salinity affect the value of mangrove biomass, carbon content, and carbon sequestration. Carbon sequestration and storage decreases with increasing temperature, pore water salinity, pH, bulk density, and sand in mangrove soils. The relatively low absorption capacity of organic C from mangroves can be caused by low rainfall, limited nutrients, and temperature, decrease in mangrove growth rate, and increase soil respiration rate (Almahasheer *et al.*, 2017). Salinity and nutrients encourage the variability of the mangrove vegetation structure. Soil and mangrove vegetation are in an alternating multivariate system. Soil-vegetation interactions are important in mangrove restoration (Cooray *et al.*, 2021).

Table 4. Environmental variables of study locations in Jepara Regency, Central Java

Variable	Kedung			Mlonggo			Keling		
	1	2	3	1	2	3	1	2	3
Physics									
pH	7.9	8.2	8.4	7.6	7.8	7.7	7.9	8	7.7
DO (mgL^{-1})	6.4	6.6	5	5.8	5.6	5.2	5.2	6.2	5.2
Temperature (°C)	32	32	32	32	32	32	32	32	32
Salinity (‰)	32	32	32	32	32	32	32	32	32
Sediment texture	sandy mud	sandy mud	sandy mud	coral sand mud	coral sand mud	coral sand mud	coral sand mud	coral sand mud	coral sand mud

Soil pH, salinity, organic matter, K, Mg, Ca, Cu, Ni, Zn, and Mn were identified as basic soil chemical properties that conserve and support mangrove vegetation (Cooray *et al*., 2021).

Soil organic carbon in undisturbed mangroves can contribute to a large proportion of the carbon stock, regardless of the vegetation stand presence (Zakaria *et al*., 2021). This study showed that the carbon sequestration capacity of rehabilitated mangroves increases with age. Carbon stock storage stabilizes after maturity (*i.e.*, >17 years) (Carnell *et al*., 2022). Saintilan *et al*. (2013) also reported that coastal vegetation types play a role in levels of carbon accumulation, storage, and carbon sources in Australia's coastal areas. The composition of age and type of mangrove forest directly affect net primary productivity and carbon sequestration potential (Sahu and Kathiresan, 2019). Species diversity, tree density, tree age, and level of disturbance significantly affect the distribution of the component patterns of mangrove carbon stocks (Alongi and Mukhopadhyay, 2015; Phillips *et al*., 2017). Furthermore, mangroves have the largest above ground biomass because of their larger and woody growth forms. Kauffman *et al*. (2018) found that mangrove carbon stocks were much higher for above ground carbon.

4. Conclusion

Mangrove rehabilitation area has a better potential for carbon sequestration. In this study, the mangrove species that showed the greatest potential was *R. mucronata* in Jepara Regency, Central Java, Indonesia. The mangrove *R. mucronata* had the highest carbon absorption content, compared to the species *A. marina*, *R. apiculata*, and *S. alba*. The amount of carbon sequestration in mangroves was influenced by the number of trees and DBH and was supported by environmental factors of pH and salinity. The more trees that grew and developed with a large DBH size affected the biomass, carbon content, and carbon sequestration of mangroves.

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Authors' Contributions

All authors have contributed to the final manuscript. The contribution of each author as follow, ANH,

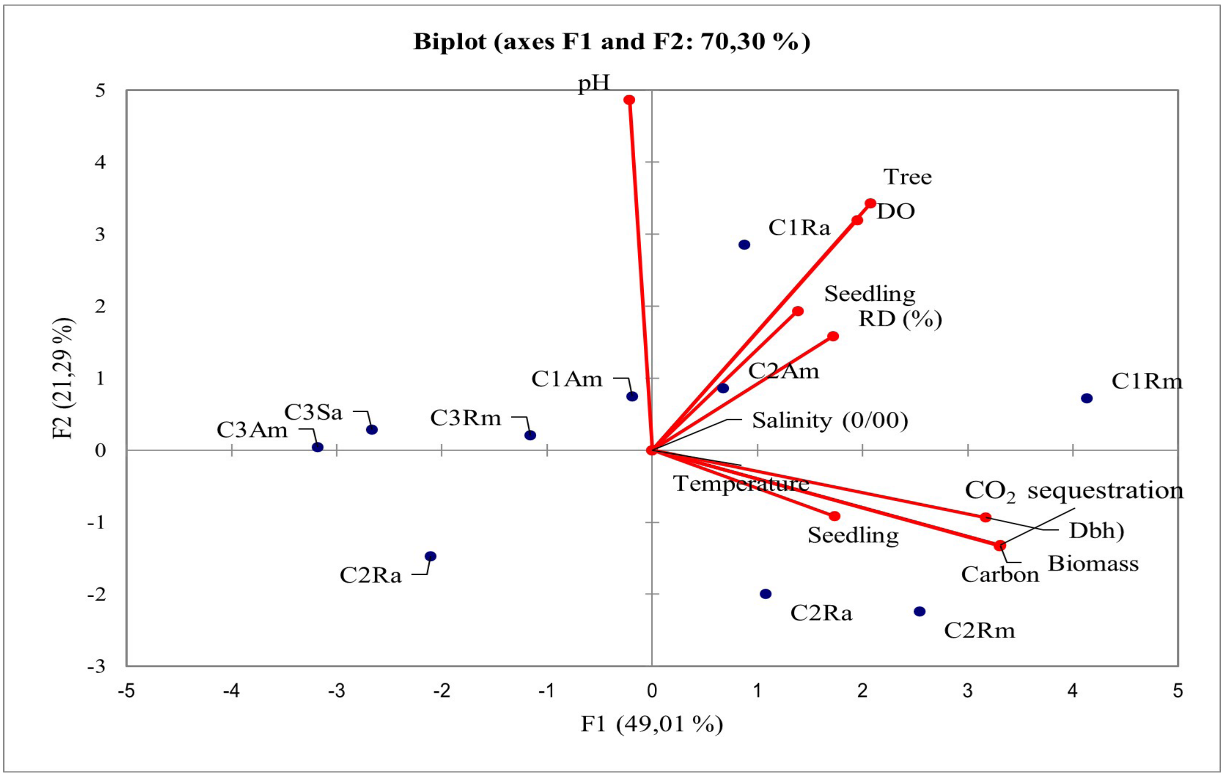

Figure 3. PCA result on the relationship between mangrove species and mangrove carbon sequestration

Note: C1 (Kedung), C2 (Mlonggo), and C3 (Keling), Am (*A. marina*), Ra (*R. apiculata*), Rm (*R. mucronata*), Sa (*S. alba*), DBH (Diameter at Breast Height)

NA, S, and MH; collected the data, drafted the manuscript, and designed the figures. ANH and NA; devised the main conceptual ideas and critical revision of the article. All authors discussed the results and contributed to the final manuscript.

Conflict of Interest

The authors declare that they have no competing interests.

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